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VLF P-STATIC NOISE REDUCTION IN AIRCRAFT
Volume II: Recommended Action

by
Robert W. Lilley

Avionics Engineering Center
Department of Electrical Engineering
Ohio University
Athens, Ohio 45701

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA •

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FINAL REPORT

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16. Abstract

Recommendations for experimentation and action to reduce p-static effects on low-frequency navigation are presented, with emphasis on awareness of p-static symptoms and cures by the aviation community. Experimentation to verify effects of new mechanical and electrical technology on p-static reduction is proposed. The potential for interference by related noise sources such as lightning discharges is noted.

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METRIC CONVERSION FACTORS

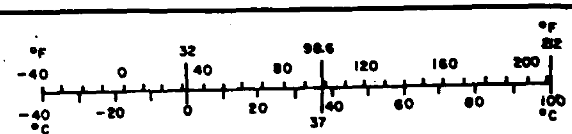
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

Volume I of this report presents current knowledge of p-static generation mechanisms and reduction techniques for aircraft. In Volume II recommendations are made for studies, experiments and actions involving the aviation community, with the overall goal of improving the p-static interference environment.

As was stated in Volume I, the expectation is that evolutionary improvements can be realized through (1) pilot and maintenance personnel education and (2) through increased attention to details of airframe and accessories design and maintenance. The physics of airframe charge/discharge during flight, of course, remains invariant. The increase in IFR operation and recent interest in low-frequency navigation systems such as Loran-C, have necessitated a review of the p-static problem.

II. RECOMMENDED ACTION BASED UPON CURRENT KNOWLEDGE

Certain actions may be taken by FAA and by the aviation community based upon current knowledge of p-static causes and effects. No call is made here for additional regulation; rather, a program of education is proposed.

A. Advisory Circular Preparation. The FAA, acting through the established Advisory Circular channels, should make current p-static knowledge available to the aviation community generally. Such a publication should take advantage of pilot experiences, prior research and observation, plus airframe and discharger manufacturers' data to educate pilots and owners.

The need for airframe dischargers in all IFR conditions should be stated, together with the need for regular inspection and replacement. Manufacturers have data, based upon experiment and observation, as to best discharger placement and number required. Maintenance personnel should heed manufacturer data on discharger service and lifetime.

Maintenance personnel should be educated as to the importance of maintaining airframe bonds during reassembly after inspections or alterations. Molded antenna structures should be replaced if cracks or punctures in the surface coating appear.

Avionics shops should be encouraged to avoid installation of bare-wire antennas for communications, navigation or ELT functions. Such antennas are excellent noise sources, with noise coupling to other onboard systems occurring even at VHF or UHF frequencies.

Static drains, often consisting of a simple resistor attached from the antenna to the airframe, can reduce arcing noise, especially if the antenna is disconnected from its avionics unit. At least, a load resistor should be placed across the antenna terminals when the antenna is actually disconnected. An open-circuit antenna is an invitation to interference.

A noncontroversial Advisory Circular can be prepared as the first step in a program of awareness and education. The items listed above are essentially just good aircraft maintenance practice. Their importance is enhanced, however, for an aircraft which is heavily used in IFR conditions. Minimization of noise sources will improve navigation and communications performance at all operating frequencies.

B. Airframe and Avionics Manufacturers. The commercial firms offering products and services to the aviation community should be encouraged to emphasize electrically-quiet airframe and avionics design. For any aircraft expected to fly in IFR conditions, airframe dischargers should be installed at points determined by a static survey of that model. Discharger design is important; badly-designed dischargers can increase noise. Factory-installed avionics should make use of low-profile, encapsulated antennas to avoid corona noise. Streamer discharge noise should be considered when making a decision to include nonconductive airframe components in a design.

Avionics manufacturers should be encouraged to test all new receiver designs under p-static conditions. Such tests are relatively uncomplicated, and may be performed with a laboratory corona generator. Static drains and appropriate AGC bandwidths should be included in designs, for optimum receiver noise performance.

C. Discharger Ramp-Check Procedures. Visual and electrical procedures for checking discharger units in the field can be prepared as a second Advisory Circular. Knowledge and equipment exists for avionics shops to provide this basic service if problems arise, or for the test to be run during airframe inspections. The test is a measurement of the high-resistance element in the discharger, to determine whether it is within manufacturer tolerances. A visual check for physical damage is also necessary. Each discharger must be checked; "spot checks" may miss a discharger which, through aging or damage has become a noise source.

III. STATIC TEST DESIGN FOR AIRCRAFT CURRENTLY IN THE FLEET

The manufacture of an electrically-quiet aircraft is followed by its operation in a variety of weather conditions, and by maintenance, modification and inspection. The aging and erosion of dischargers and antenna surface coatings, attachment of additional avionics units and their antennas, and changes in airframe components through removal and replacement during inspection can all cause increases in locally-generated noise. As was presented in Volume I of this report, the observable effects of p-static on aircraft avionics systems can take many forms, and a pilot/owner may waste time and money on avionics service when the problem is really external to the electronic systems.

The design of a convenient testing method for ramp-or hangar-checking an aircraft for discharge noise sources is needed, to permit rapid identification and correction of noise sources. Such tests may take the form of a simple high-voltage generator (even a "Megger" might do the job), with a noise probe in the form of a small radio receiver. Airframe noise sources may then be located manually, by probing various points on the airframe.

These whole-airframe static surveys are routinely performed at only a few locations at present. A test procedure, with suitable equipment specifications and safety procedures, needs to be formulated such that an avionics maintenance shop may economically make static surveys available to the flying public.

IV. RECOMMENDED INVESTIGATION AND EXPERIMENTATION

Several areas should be investigated further to gain understanding of airborne noise phenomena and effective countermeasures. The following sections outline studies or experiments recommended for consideration.

A. Refinement and Simplification of Ramp Test Methods. Convenient and effective ramp checks of aircraft operated in IFR conditions are required for evaluation of corona, arcing and streamering noise sources. Test procedures should be carried out on various airframes typical of the general-aviation fleet. First, a complete static survey of each airframe should determine the presence and location of noise sources as baseline data. Then, simplified versions of the test procedure should be designed, and each ramp-check procedure should be performed to determine its validity as a test for airframe noise. The goal should be to define a static test which uses inexpensive instrumentation and safe procedures, while retaining sensitivity to noise sources. It should be shown that application of such a ramp-test procedure to typical fleet aircraft will reduce discharge noise to levels which will not adversely affect navigation at low frequencies.

B. Evaluation and Reduction of Streamer-Discharge Noise. The increase in non-metallic airframe components such as wingtips, radomes and windscreens made of glass-fiber or acrylic materials increases the streamer-discharge problem. Accumulated surface charge on these materials, lacking a conductive path to the airframe dischargers, builds up until surface discharges travel along the dielectric, finally reaching a conductive surface. Thin conductive coatings can be applied to the surface to limit the streamer discharge, but such external treatment is exposed to erosion and damage. Truax [1] has suggested an interior flash coating, bonded to the airframe, with an array of conductive points through the dielectric to allow the surface charge to be conducted to the interior conductor. Spacing between the conductive points determines the potential which may be supported as surface charge on the dielectric.

A similar technique may be employed to avoid streamer discharges on the windscreen surface. Either a grid of very fine wires may be embedded in the windscreen, or a conductive sheet may be laminated between windscreen layers, with exposure to the outside surface at regular intervals. This technique is experimental at this writing. A commercial clear, conductive acrylic material is available from Tecknit [2].

Both the interior-coated glass-fiber airframe components and windscreen materials require evaluation both in the laboratory and in flight. Measurement of streamer discharge currents of treated and non-treated wingtip elements should be carried out using static-test and flight checks. Windscreen materials require static-test and flight measurement of streamer currents, and laboratory and flight evaluation of effects upon transparency and visibility in all lighting conditions.

C. Low-Frequency Navigation Antennas. A comparative study of currently-available Loran-C antennas should be carried out, in static-test and in flight. Test goals should be to generate comparison data by antenna type, and to provide real input data for receiver evaluation (see "D" below).

The desirability of wind-tunnel testing for antennas should be evaluated against corona-point testing using trailing-edge charge collectors to simulate airspeed effects. An antenna test bed should be validated using the best method.

The decoupled (top-and-bottom mounted) E-field antenna array introduced by Tanner and Nanevicz [3] and under current study for Omega use by Baltzer [4] should be evaluated for Loran-C use, if current evaluations show additional promising results.

The use of resistive coatings for molded antenna structures should be considered, with resistivity a parameter, and noise generation and navigation signal degradation as dependent variables.

The use of H-field antennas should be reconsidered, in the light of low-cost general-aviation Loran-C equipment which may not require sensitivity to the Loran-C phase code. Such antennas offer protection from p-static effects if properly located on the airframe.

Low-cost modifications for existing bare-metal antennas should be sought, to remove the conductive surface from the airstream. Coatings or sleeves may be developed to reduce or eliminate corona discharge from such elements.

D. Loran-C Receiver Design and Operation. Continued work should take place on Loran-C RF design, emphasizing evaluation of intelligent noise blankers, proof of AGC bandwidth effects on p-static performance, provision of static drain circuitry, and processor software which takes p-static noise phenomena into account, where possible. Convenient bench tests for noise performance under corona conditions require design and validation against flight data.

New receiver designs for general aviation should consider the H-field antenna as a sensor, recognizing that for low-cost omniazimuthal coverage, the receiver may be required to operate in the absence of the Loran-C phase code due to signal squaring at the antenna coupler to avoid aircraft body-angle effects.

At least a sample of two Loran-C receivers should be flown in known p-static conditions, either actual or simulated by biased discharger [5], to assess directly the performance effects in hard-limited and linear receivers caused by aircraft noise sources. Effects of AGC bandwidth and static drain presence should be demonstrated.

The biased discharger simulates triboelectric airframe charging by causing ions to leave the airframe via a tail-cone discharger. This discharger is connected to a high-voltage power supply on board the aircraft. The loss of ions via the tail discharger causes the airframe to assume a potential with respect to surrounding air. With potentials above the discharge threshold, airframe discharge mechanisms become operative, simulating the discharges present in actual weather conditions conducive to p-static.

The value of the biased discharger lies in its ability to create realistic airframe discharges in clear air, reducing flight time and schedule delays required by flight in weather of opportunity.

E. Effects of Lightning Discharge on Loran-C Navigation Systems. While not a p-static phenomenon, the effects of lightning on Loran-C navigation require investigation. As reported in Volume I of this report, little published information is available on specific Loran-C lightning effects as reflected by hard-limited or linear receivers. The routine use of Loran-C for enroute navigation and approach guidance in IFR conditions will require intelligent receiver processor handling of the inevitable loss of signal during a lightning return stroke at close range, with appropriate pilot warning of temporary data loss or flag event if guidance is degraded beyond enroute or approach tolerances.

One area for investigation lies in this receiver intelligence, in that if a trigger mechanism can be found, the receiver may be able to predict a forthcoming lightning event. Armed with such a prediction, receiver software may take appropriate actions to maximize the accuracy of pilot indications during the event itself. Detection of the stepped leader, the precursor to the main lightning event, may provide this trigger.

Lightning effects should be studied as a function of field strength in the vicinity of the aircraft, the number of individual strokes in a total flash, receiver and airframe configuration, and the simultaneous presence of p-static discharge noise. Such tests may be performed in existing high-voltage test facilities [6].

F. <u>Related Issues for Investigation</u>. It is known [7] that corona discharge occurs as a series of pulses, with repetition rate dependent upon the potential driving the corona discharge. The range of repetition rates observed in aircraft-generated corona can vary from 1 Hz to 1 MHz. This range includes the 30, 90 and 150 Hz frequencies used for audio processing of VOR and ILS signals, digital and analog processing of MLS signals in addition to the Omega and Loran-C navigation frequencies. Study and experiment should determine the extent to which the "low-frequency navigation" carried out at these audio frequencies can be affected by corona-generated RF noise, modulated at the critical repetition rates. The search carried out for this study found no literature on this subject exists.

V. CONCLUSIONS

Several clear paths of action are recommended which, if pursued, will lead to increased knowledge and awareness of aircraft discharge noise phenomena and their effects upon navigation and communications. Investigation of practical solutions for discharge noise problems will permit informed design and installation of avionics systems for use in conditions where p-static is encountered. These solutions, combined with routine maintenance of airframe noise integrity through regular static evaluations will result in enhanced safety and utility, and will improve low-frequency navigation system performance.

VI. REFERENCES

[1] Truax, R., President, TCO Company, Ft. Myers, Florida, conversation with R. Lilley, March 13, 1980.

[2] Tecknit Corporation, Sales Catalog, EMI Shielding Division, Santa Barbara, California, 1979, pp. 61 ff.

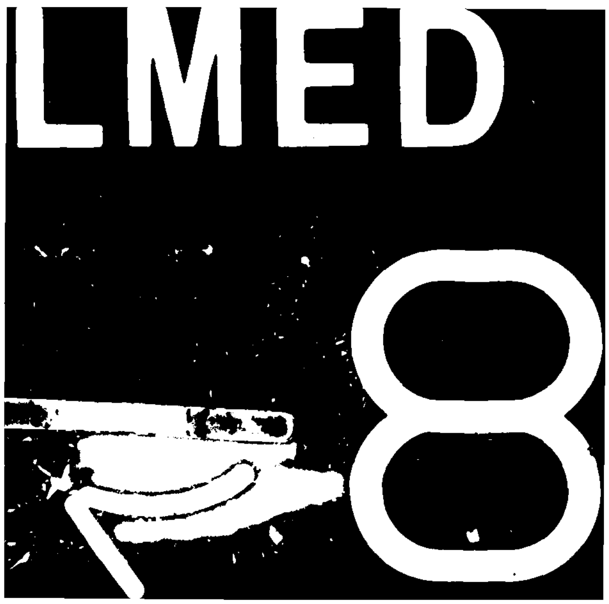
[3] Tanner, R. L., and Nanevicz, J. E., "Precipitation Charging and Corona-Generated Interference in Aircraft", Stanford Research Institute, Technical Report 73, April 1961, p. 137.

[4] Contract FA75WA-3662, Task II--Noise-Cancellation Antenna, with Systems Control, Inc., Palo Alto, California.

[5] Tanner, R. L., and Nanevicz, J. E., "Precipitation Charging and Corona-Generated Interference in Aircraft", Stanford Research Institute, Technical Report 73, April 1961.

[6] The Electromagnetic Hazards Group, U. S. Air Force, Wright-Patterson AFB, Ohio, can generate simulated lightning strokes using 200 KV, 30 KA sources, with maximum voltages to 1.5 MV and maximum current to 250 KA.

[7] Truax, R., President, TCO Company, Ft. Myers, Florida, conversation with R. Lilley, November 13, 1980.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